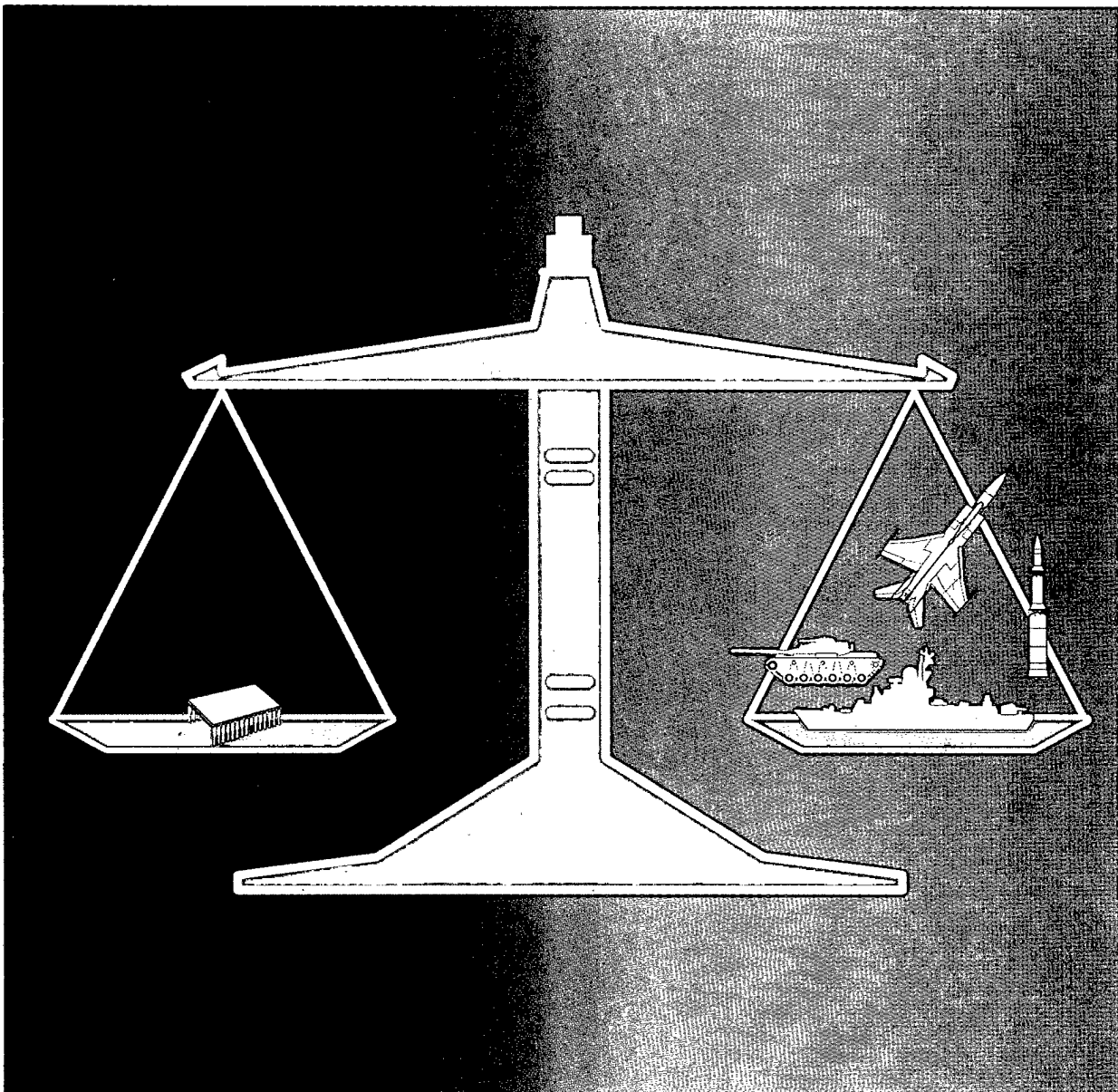


## ***National Security And Export Controls: A Decision Aid***



# National Security and Export Controls: A Decision Aid

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## Introduction

The Technology Transfer Assessment Center (TTAC) has worked for two years to develop a decision aid to enhance the utility of intelligence information and analysis in export control policy. Our work suggests that intelligence can provide a crucial input in the national security debate over strategic commodity exports. The TTAC Methodology, as demonstrated in this Prototype, offers new approaches for processing and presenting intelligence in an useable and understandable form. This prototype also illustrates that intelligence offers the decisionmaker useful inputs from which to devise policy alternatives.

The strength of the TTAC Methodology is that it identifies Western technologies and equipments which are required for the development and production of future Soviet military systems. Unlike the current system, which is heavily biased toward developing a universal set of "militarily critical technologies," the TTAC system returns to the original reason for US and multinational export controls—Soviet military needs. At a minimum, this provides decisionmakers with a list of those items which should be considered for export control. After the policymaker examines other factors, such as foreign availability, economic costs, and foreign policy constraints, the Methodology provides a credible justification—regardless of the decision—which can be used both at home and abroad.

## Case Studies

The original proof-of-concept for the Methodology done in 1987 focused on Soviet requirements for microelectronics technology and equipment. In order to build on that effort, we developed case studies using six types of microelectronics production equipment: low pressure chemical vapor deposition (LPCVD); ion implantation; automatic wire bonding; computer-aided design (CAD) equipment and

software; ion milling; and mask making, inspection, and repair equipment.

In each case, TTAC has assessed Soviet current and future capabilities to produce this equipment, Soviet current and future military needs for this equipment (based on military systems in need of this technology), and judged the relative importance of the equipment to Moscow. The overall results are presented in figure 1, found in the fold-out at the end of this paper.

### *Low Pressure Chemical Vapor Deposition:*

Low Pressure Chemical Vapor Deposition (LPCVD) is one of the most important methods of material deposition used in fabricating ICs. Integrated circuits are formed by precisely depositing a series of extremely thin layers of materials—either different materials or the same material but with different electrical properties—on selective areas of the IC. These materials—usually oxides, nitrides, or silicides—must be ultra-pure, of uniform thickness across the circuit, and able to adequately cover a variety of holes and steps on the circuit's surface. LPCVD is the best method of forming the layers of these materials. Other methods do not produce layers of the same quality as LPCVD processes and hence are much less attractive to the USSR for technology acquisition.

Several CVD variants exist, the most important being low pressure (LPCVD), plasma enhanced (PECVD) and metal organic (MOCVD).<sup>\*</sup> Virtually all CVD systems used in microelectronics fabrication at the LSI level and above are low pressure systems. CVD

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<sup>\*</sup> Liquid phase epitaxy (LPE) and MOCVD are used primarily for growing gallium arsenide and other III-V semiconductor compounds. We did not include these non-silicon materials in our original study relating weapons to technologies, but acquisition of LPE or MOCVD equipment would assist the USSR in its gallium arsenide development and production efforts.

performance parameters are related to the pressures, flows, and percentage of the gases which are used. Digital computers are not absolutely required for LSI and first generation VLSI use, but 2nd generation VLSI and VHSIC capabilities require the use of a digital computer connected to a mass flow controller.

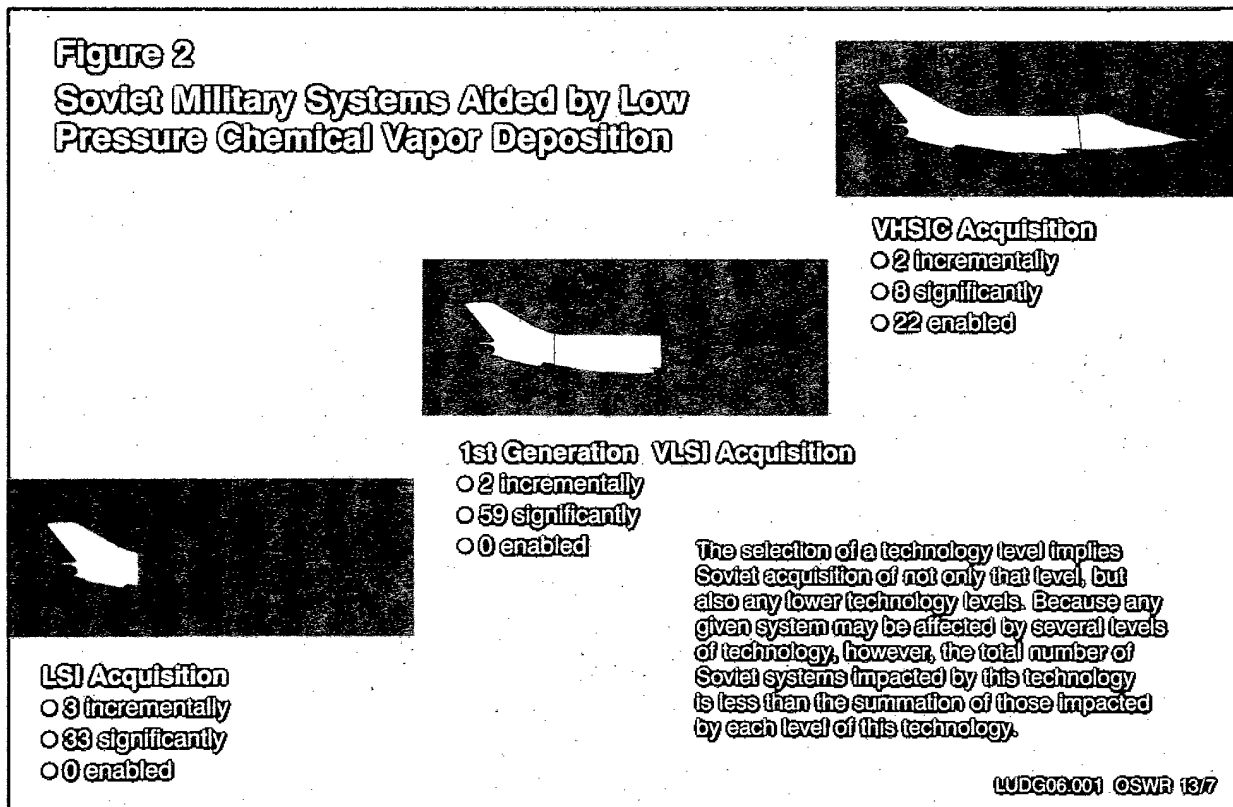
The Soviet Union lags the West in CVD capabilities. As IC linewidths are reduced, the thickness of the various layers on the IC must also become thinner. The Soviets have difficulty in producing thin, high-purity layers in a controlled, repeatable manner. As the Soviets attempt to move forward into the 2nd generation VLSI range, LPCVD problems will seriously hamper Soviet progress.

All LPCVD systems currently are CoCom controlled. These systems are made by several CoCom nations, with the industry leaders located in the United States, Japan, West Germany, and the United Kingdom. The major non-CoCom manufacturer is Timesa Microelectronics S.A. of Switzerland. Some of these systems will be essential to produce the ICs required for Soviet military programs, many will be beneficial for production of Soviet military ICs, and some will

not be required for Soviet military IC production. We have identified those Soviet military systems which will be placed into operation by the year 2000 and assessed the level of microelectronics (LSI, 1st generation VLSI, 2nd generation VLSI, or VHSIC) which each will require to meet its performance specifications. We also have identified the characteristics of LPCVD systems which are necessary to produce each of these generational levels of microelectronics and their corresponding impact on development and production of future Soviet military systems. As a result, we can provide the following observations about those characteristics of LPCVD systems which are required for each level of microelectronics.

- In order to limit LPCVD system capabilities to those required for production of LSI-level microelectronics, they must *not* be equipable with digital controllers, vertically supported radiant-heat reactors, or mass flow controllers. If the Soviets acquired LPCVD systems capable of no more than LSI level production, it would aid in their development of 36 out of the 77 expected military systems that we identified, and of these: 3 systems

**Figure 2**  
**Soviet Military Systems Aided by Low Pressure Chemical Vapor Deposition**



would be aided incrementally but could proceed without the acquisition, 33 systems would be aided significantly and would suffer degraded performance without the acquisition, but no military systems would require the acquisition to such an extent that they would totally fail in their missions.

- In order to limit LPCVD system capabilities to those required for production of 1st generation VLSI-level microelectronics, they must *not* be equippable with mass flow controllers. If the Soviet acquired LPCVD systems capable of no more than 1st generation VLSI level production, it would satisfy the LSI needs of the previous military systems, and in addition to satisfying those needs would further aid Soviet development of 61 out of 77 expected military systems that we identified, and of these: 2 systems would be aided incrementally but could proceed without the acquisition, 59 systems would be aided significantly and would suffer degraded performance without the acquisition, but no military systems would require the acquisition to such an extent that they would totally fail in their missions.
- LPCVD systems needed for producing 2nd generation VLSI and VHSIC-level microelectronics are state-of-the-art LPCVD systems and require *all* the above options specifically excluded from the LSI and 1st generation VLSI-capable systems. If the Soviets acquired LPCVD systems capable of 2nd generation VLSI and VHSIC production, it would satisfy the LSI and 1st generation VLSI needs of the previous military systems, and in addition to satisfying those needs would further aid Soviet development of 32 out of 77 expected military systems that we identified, and of these: 2 systems would be aided incrementally but could proceed without the acquisition, 8 systems would be aided significantly and would suffer degraded performance without the acquisition, and 22 systems would require the acquisition to such an extent that they would totally fail in their missions without this technology.

### *Ion Implantation:*

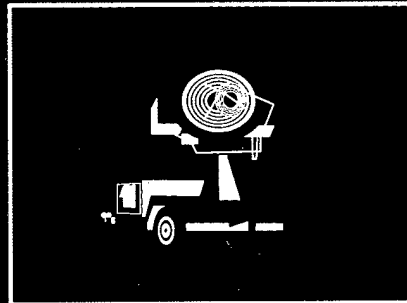
Ion implanters are essential to all IC manufacturing covered in this study. Integrated circuits are formed by isolating precise areas of the silicon wafer's surface and altering the electrical characteristics of those areas. The electrical characteristics of ultra-pure, uncharged silicon are altered by adding small quantities of impurities—dopants—to the wafer. These dopants either add to or subtract from the electrons in the silicon, creating charged areas and allowing current flow. Diffusion, the traditional method of adding dopants, relies on a furnace to steadily diffuse dopants chemicals from the wafer surface into the silicon. Implantation, a more advanced method, is the direct injection of a beam of dopant atoms into the wafer. At present ion implantation is the only way to accomplish the highly controlled shallow dopings which are required as circuit dimensions shrink.

Implanters are characterized by their accelerating potential, current, control electronics, and electron source. Most of these features, however, are important only in optimizing an implanter for a particular application. Virtually any implanter can be used in manufacturing any generational level of IC.

The Soviet Union lags the West in ion implantation. Implanters rely on digital computer control to ensure reliable and repeatable dopings. This area is a problem for Soviet ion implanters. Before 1980 Soviet ion implanters were even further behind the Western state-of-the-art. Because of extensive technology transfer from a Western firm, however, the Soviets were able to substantially improve their indigenous capabilities.

All ion implanters currently are CoCom-controlled. These implantation systems are made by several CoCom nations, with the industry leaders located in the United States and Japan. The major non-CoCom manufacturer is Balzers of Liechtenstein. We also have identified the impact of these implantation systems on development and production of future Soviet military systems. Ion implantation systems can not be divided into generational categories because most ion implanters can be adapted to produce any generation of microelectronics. Therefore, any Soviet acquisition of ion implanters would satisfy Soviet requirements up to the VHSIC level.

**Figure 3**  
**Soviet Military Systems Aided**  
**by Ion Implantation**



**VHSIC Acquisition**

- 2 incrementally
- 40 significantly
- 22 enabled

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- Ion implanters capable of VHSIC production are state-of-the-art systems. If the Soviets acquired ion implanters capable of VHSIC production, it would aid Soviet development of 64 out of 77 expected military systems that we identified, and of these: 2 systems would be aided incrementally but could proceed without the acquisition, 40 systems would be aided significantly and would suffer degraded performance without the acquisition, and 22 systems would require the acquisition to such an extent that they would totally fail in their missions without this technology.

***Automatic Wire Bonding:***

Automatic wire bonding is essential to connect the integrated circuit electrically to its lead frame. The lead frame either joins with or serves as the IC's external pins. These pins provide the IC's connection to the printed circuit board on which the IC is mounted. The surface of an advanced IC is coated with aluminum interconnection metallization. This metallization can occupy as much as 60 percent of the circuit's surface

area. The number of interconnections increased dramatically as more transistors are placed on an IC. The area devoted to metallization is therefore likely to increase, leaving smaller areas available for bond pads. This will place greater constraints on bonders, which will have to accurately bond thin aluminum wires to a much smaller bond pad target.

Wire bonders are characterized by bonding method (usually ultrasonic or thermocompression), bonding speed, and bond placement accuracy. Bonding speed is important for throughput, but does not limit the sophistication of the IC being bonded.

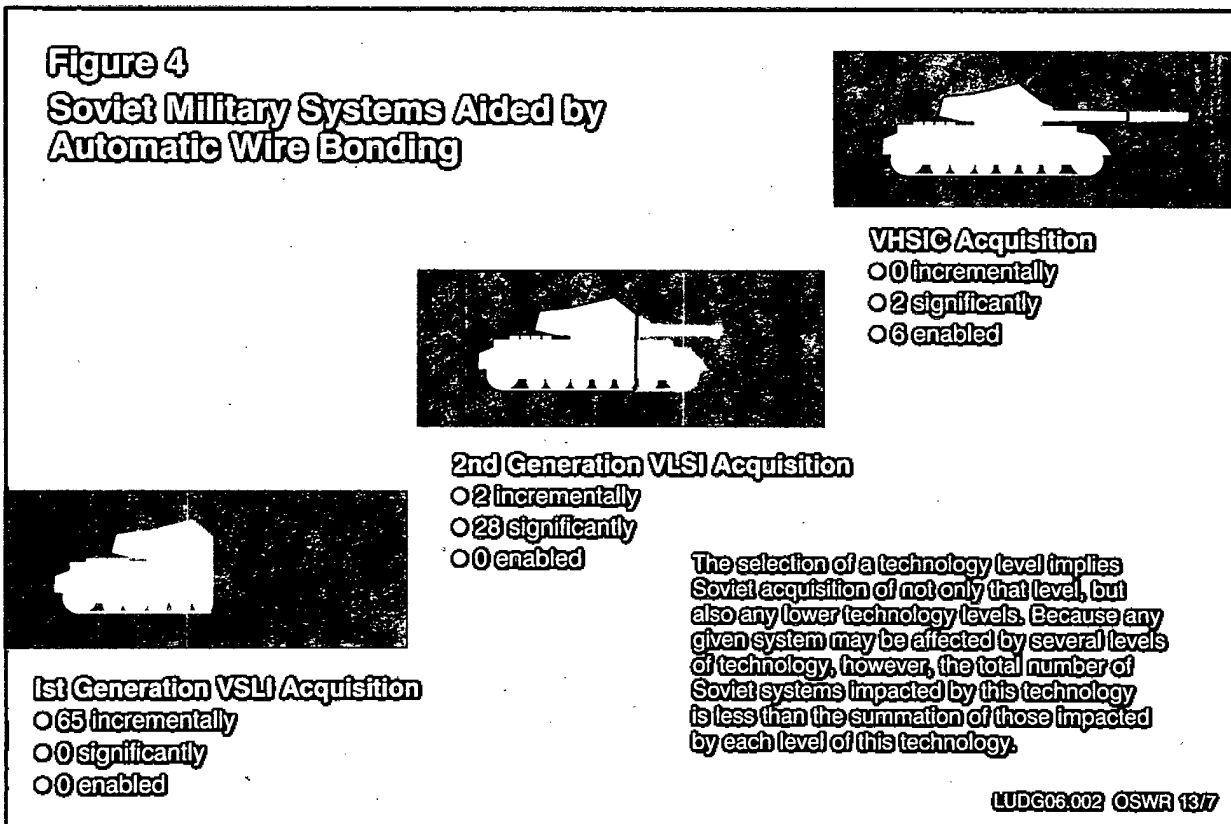
The Soviet Union lags the West in wire bonders. Many Soviet wire bonds pull free from their bond pads, are off-center, or are poorly formed. These problems affect IC reliability, important for military systems. Soviet bonders also generally use thermocompression bonding with gold wires, whereas most military-specification ICs require ultrasonic bonding with aluminum wires.

All digitally-controlled automatic wire bonders currently are CoCom-controlled. These wire bonders are

made by several CoCom nations, with the industry leaders located in the United States and Japan. The major non-CoCom manufacturers are ESEC and Farco of Switzerland. Of the wire bonders available in the West, some will be essential to produce the ICs required for Soviet military programs, many will be beneficial for production of Soviet military ICs, and some will not be required for Soviet military IC production.

- In order to limit wire bonder capabilities to those required for production of 1st generation VLSI level microelectronics, they must *not* be equippable with ultrasonic bonding and must *not* be capable of placing bonds with greater than 2.5 micron accuracy. If the Soviets acquired wire bonders capable of no more than 1st generation VLSI level production, it would aid in their development of 65 out of 77 expected military systems that we identified, and of these all would be aided incrementally but could proceed without the acquisition. No military systems would suffer significantly degraded performance without the acquisition.
- In order to limit wire bonder capabilities to those required for production of 2nd generation VLSI level microelectronics, they must *not* be capable of placing bonds with greater than 2.5 micron accuracy. If the Soviets acquired wire bonders capable of no more than 2nd generation VLSI level production, it would satisfy the 1st generation VLSI needs of the previous military systems, and in addition to satisfying those needs would further aid Soviet development of 30 out of 77 expected military systems that we identified, and of these: 2 systems would be aided incrementally but could proceed without the acquisition, 28 systems would be aided significantly and would suffer degraded performance without the acquisition, but no military systems would require the acquisition to such an extent that they would totally fail in their missions.
- Wire bonders needed for producing VHSIC-level microelectronics are state-of-the-art wire bonders and require *all* the above characteristics. If the Soviets acquired wire

**Figure 4**  
**Soviet Military Systems Aided by Automatic Wire Bonding**



bonders capable of VHSIC production, it would satisfy the 2nd generation VLSI needs of the previous military systems, and in addition to satisfying those needs would further aid Soviet development of 8 out of 77 expected military systems that we identified, and of these: 2 systems would be aided significantly and would suffer degraded performance without the acquisition, and 6 systems would require the acquisition to such an extent that they would totally fail in their missions without this technology.

#### ***Computer Aided Design Equipment and Software:***

Computer aided design (CAD) equipment and software is an essential element of current and future IC production. Simulation and layout of almost all LSI, VLSI, and VHSIC ICs is done with the use of CAD. Hand layout is so time-consuming and error-prone that most of the designs are done primarily with CAD. Circuit designers build up the final circuit design using a mix and match approach. Established designs for various circuit functions are chosen from a menu and placed in the design. These functions are checked using the simulation capabilities of the CAD system, which checks for acceptable timing and performance. After all these circuit functions are incorporated along with logic circuitry specifically tailored for that IC, the CAD system automatically routes and optimizes the interconnection metallization. Design engineers only contribute after the CAD equipment has done all the interconnections it can, usually with more than 90 percent of the layout complete.

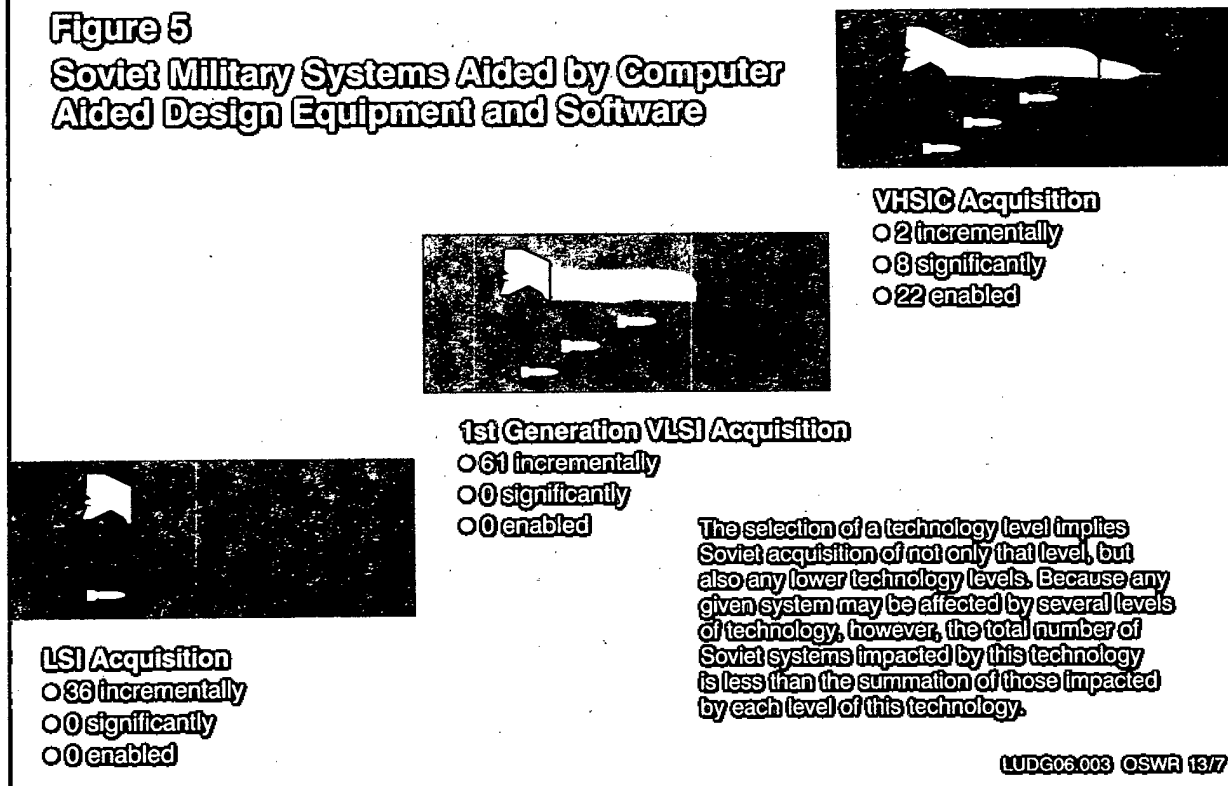
CAD systems are characterized by their maximum transistor storage capacity, simulation capabilities, routing capabilities, and computer processing method. The more advanced CAD systems are able to efficiently manipulate many thousand individual transistor circuit elements into a space-saving design, automatically route interconnections between these transistors, and simulate the operation of various circuit elements either singly or in combination to verify that they function as intended. The most advanced CAD systems will use newly developed parallel processing computational techniques to maximize their speed.

The Soviet Union lags far behind the West in CAD capabilities. While the Soviets have difficulties in producing advanced ICs (contributing to a Western IC technology lead of 8-9 years), the Soviets have even more difficulty incorporating the ICs they do produce into computer systems. In CAD systems the Soviets lag by well over 10 years, and do not appear to be catching up.

Although current CoCom controls allow some types of CAD equipment to be sold to the Warsaw Pact, in actual fact the control threshold is drawn so low that all useful Western CAD systems are controlled. The CAD equipment market is dominated by the United States. Systems supplied by non-US manufacturers do not provide desirable alternatives. We have identified the characteristics of CAD systems which are necessary to produce these generational levels of microelectronics required for Soviet military systems.

- In order to limit CAD system capabilities to those required for production of LSI-level microelectronics, they must *not* be capable of storing and processing more than 20,000 transistors, performing multichip simulation, performing gate array routing, automatically performing application-specific integrated circuit (ASIC) routing, or using parallel processing. If the Soviets acquired CAD systems capable of no more than LSI level production, it would aid in their development of 36 out of the 77 expected military systems that we identified; all would be aided incrementally but could proceed without the acquisition. No military systems would suffer significantly degraded performance without the acquisition.
- In order to limit CAD system capabilities to those required for production of 1st generation VLSI-level microelectronics, they must *not* be capable of storing and processing more than 200,000 transistors, performing multichip simulation, performing gate array routing, automatically performing application-specific integrated circuit (ASIC) routing, or using parallel processing. If the Soviet acquired CAD systems capable of no more than 1st generation VLSI level production, it would satisfy the LSI needs of the pre-

**Figure 5**  
**Soviet Military Systems Aided by Computer**  
**Aided Design Equipment and Software**



vious military systems, and in addition to satisfying those needs would further aid Soviet development of 61 out of 77 expected military systems that we identified, and of these all would be aided incrementally but could proceed without the acquisition. No military systems would suffer significantly degraded performance without the acquisition.

- CAD systems needed for producing 2nd generation VLSI and VHSIC-level microelectronics are state-of-the-art CAD systems and require *all* the above options specifically excluded from the LSI and 1st generation VLSI-capable systems. If the Soviets acquired CAD systems capable of 2nd generation VLSI and VHSIC production, it would satisfy the LSI and 1st generation VLSI needs of the previous military systems, and in addition to satisfying those needs would further aid Soviet development of 32 out of 77 expected military systems that we identified, and of these: 2 systems would be aided in-

crementally but could proceed without the acquisition, 8 systems would be aided significantly and would suffer degraded performance without the acquisition, and 22 systems would require the acquisition to such an extent that they would totally fail in their missions.

#### ***Ion Milling:***

Ion milling is not currently required for IC production although it is CoCom-controlled for that purpose. Ion milling has been very useful in industries other than microelectronics and was originally thought to be valuable in manufacturing VLSI and VHSIC devices. In microelectronics, ion milling is a form of etching used to define the circuit pattern on the IC. Despite many technical journal articles the technique has not been found useful because it lacks material selectivity—that is to say it etches all materials equally instead of etching only selected materials. In addition, exact detection of the end-point of the etching process has proven difficult. For these reasons ion milling is not suitable for advanced IC fabrication. Since

fabrication of less sophisticated ICs can be accomplished using etchers the USSR already possesses, we conclude that there is no national security reason to control ion millers for use in microelectronics fabrication.

This example demonstrates a case in which the Methodology can be used to identify an area which is subject to unnecessary restrictions. Using this information, the policymaker can determine whether or not to continue to control ion millers. There are no explicit costs to the West in terms of additional Soviet military systems which will benefit from access to ICs produced using ion millers.

#### ***Mask Making, Inspection, and Repair:***

Mask making, inspection, and repair systems are essential, fundamental elements in IC production. Masks used in microelectronics manufacturing are high-quality glass substrates coated with an extremely thin and uniform layer of metal. This metal layer, often chrome, is selectively etched to form the circuit pattern to be transferred on to the wafer as in a stencil. Often the circuit pattern is drawn on the mask enlarged by a factor of 5 or 10 and then projected through lenses to reduce the pattern to the desired size. These enlarged masks are called reticles. After the masks or reticles are made, they must be inspected for defects. Large defects, or even small defects in critical locations, can cause decreased production yield or reduced performance. Some defects can be repaired, saving the mask or reticle. Repair systems use various optical and non-optical methods to repair these defects.

Mask making equipment is characterized by the minimum useful line width which can be patterned on the mask and by the patterning method—optical or non-optical. Mask inspection equipment is characterized by the minimum defect size which can be detected. Mask repair systems are characterized by the repair method—optical or non-optical.

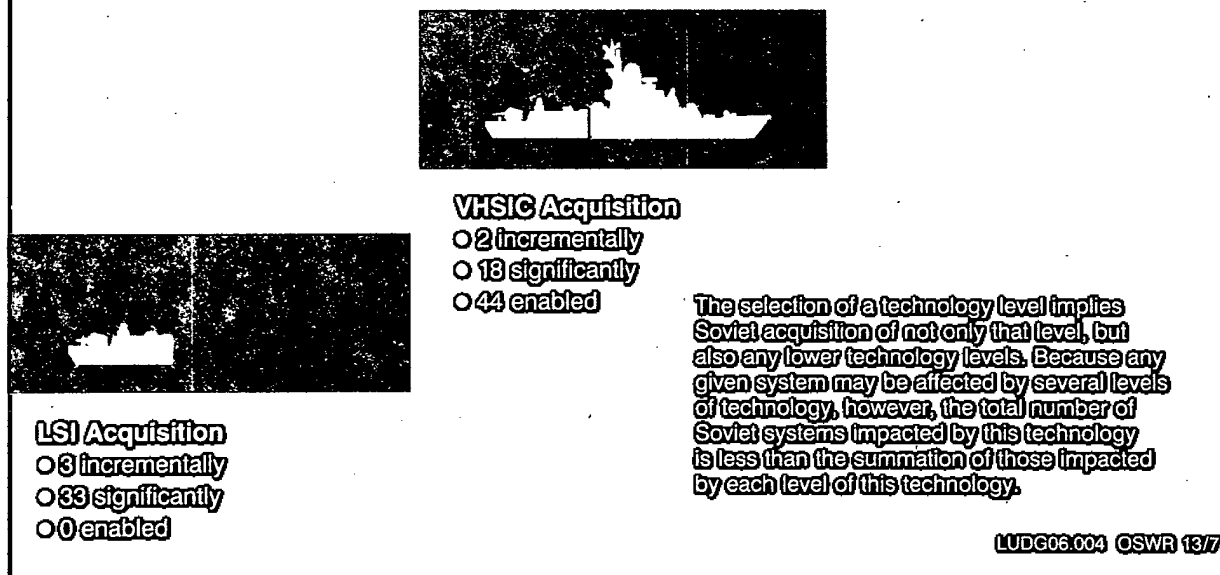
The Soviet Union lags behind the West in all these areas. Mask making depends upon high-resolution optics and mechanical stepping systems, mask inspection equipment depends upon high-resolution optics and computer scanning and comparison techniques, and mask repair systems depend upon high-precision

beam control. All these areas have been problems for the Soviets, largely because of systemic problems with high-precision equipment that requires consistently high quality control.

Current CoCom controls on these systems are applied unevenly, with controls placed on mask makers using optical pattern generators—useful primarily for LSI production, and no controls on mask repair systems using focussed ion beams—ideal for IC fabrication up to the VHSIC level. Furthermore, controls on mask inspection equipment are specified to control systems capable of resolutions of about 1/4 micron on masks with a projection ratio of 1-to-1 (masks which are not drawn enlarged for subsequent optical reduction). A 1/4 micron defect on a 1-to-1 mask would thus result in a 1/4 micron defect on the wafer after projection. Current controls, therefore, are intended to limit mask inspection systems capable of detecting defects in masks which would cause defects on the wafer smaller than 1/4 micron. But *reticles*, on the other hand, have projection ratios of up to 10-to-1 to reduce errors by a factor of 10, and a resolution of 1/4 micron on such a non-controlled reticle inspection system equates to resolution of 1/40 micron on the wafer—far beyond even VHSIC production levels. The mask making, inspection, and repair equipment market is dominated by the United States and Japan. Systems supplied by other manufacturers do not compare to US or Japanese systems.

- In order to continue the current practice of limiting mask making system capabilities to those required for production of LSI-level microelectronics, they must *not* be capable of producing useful line widths less than 3.5 microns, or of mask-making using electron-beam techniques. In order to limit mask and reticle inspection system capabilities to those required for production of LSI-level microelectronics, they must *not* be capable of comparison with a resolution of 10 microns or finer. This would be a significant tightening over current controls on inspection systems. If the Soviets continue to acquire mask making systems and mask and reticle inspection systems capable of LSI level production, it will continue to aid in their development of 36 out of the 77 expected military systems that we identified, and of these: 3 systems

**Figure 6**  
**Soviet Military Systems Aided by Mask**  
**Making and Inspection Equipment**



would be aided incrementally but could proceed without the acquisition, 33 systems would be aided significantly and would suffer degraded performance without the acquisition, but no military systems would require the acquisition to such an extent that they would totally fail in their missions.

- Mask making and inspection systems capable of use beyond the LSI-level would satisfy production requirements up to and including the VHSIC level. If the Soviets acquired these mask making and inspection systems, it

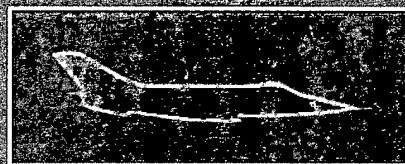
would satisfy the LSI needs of the previous military systems, and in addition to satisfying those needs would further aid Soviet development of 64 out of 77 expected military systems that we identified, and of these: 2 systems would be aided incrementally but could proceed without the acquisition, 21 systems would be aided significantly and would suffer degraded performance without the acquisition, and 44 systems would require the acquisition to such an extent that they would totally fail in their missions without this technology.

- In the case of mask repair systems, there are no options which permit distinction between level of technology. *All* photo-optical and *non-photo-optical* repair systems, including the state-of-the-art focussed ion beam repair systems, are becoming very important in VLSI and VHSIC production. These non-photo-optical systems are not presently covered under current controls on photo-optical repair systems. If the Soviets acquired mask repair systems capable of VHSIC production, it would aid Soviet development of 67 out of 77 expected military systems that we identified, and of these: 2 systems would be aided incrementally but could proceed without the acquisition, 21 systems would be aided significantly and would suffer degraded performance without the acquisition, and 44 systems would require the acquisition to such an extent that they would totally fail in their missions without this technology.

## Conclusions

In our six case studies, we found that one type of equipment which now is CoCom-controlled—ion millers—should not be controlled if the only criteria is Soviet need. Another—focussed ion beam mask repair systems—should be controlled under the same criteria. In the areas of low pressure chemical vapor deposition, automatic wire bonding, and computer aided design equipment we found that there are alternatives to the current control structure which can be based on the equipment capable of specific levels of production. In the areas of ion implantation and mask making, inspection, and repair we found that there are basically only two export control options: control everything or release everything.

**Figure 7**  
**Soviet Military Systems Aided by**  
**Mask Repair Equipment**



### VHSIC Acquisition

- 2 incrementally
- 21 significantly
- 44 enabled

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In summary, the TTAC Methodology can provide the necessary information for policymakers to consider in debating an export control decision. There are specific performance parameters for many types of equipment which limit production to a given generation level. By providing a series of options together with a summary of the national security impact of the various options, we believe we can assist the policymaker to weigh the different aspects of national security, economic competitiveness, foreign policy, foreign availability, and controllability in making the export control decision.

## Appendix

### Framework

Before we could begin our case studies it was necessary to extend our existing subsystem-to-component and component-to-technology weighting factors to take into account the differences in importance between the 24 microelectronics equipment types identified in our proof-of-concept paper. We added an additional weighting factor of High/Medium/Low to establish how important improvements over current Soviet equipment capabilities would be to achieving LSI, 1st generation VLSI, 2nd generation VLSI, and VHSIC capabilities. These new weighting factors are shown in table 1.

**Table 1**

	LSI	1st VLSI	2nd VLSI	VHSIC
Clean-Room Technology	L	M	M	H
Automated Production	L	L	L	H
Parametric Testers	L	M	H	H
Materials Characterization	L	M	H	H
Polycrystalline Silicon	L	L	L	M
Czochralski Crystal Pullers	-	M	H	H
Vapor-Phase Epitaxy	L	L	L	M
Molecular-Beam Epitaxy	-	-	L	H
Layout Know-How	-	-	M	H
Gate Know-How	-	L	M	H
Low Pressure Chemical Vapor Deposition	M	M	H	H
Ion Implantation	-	M	H	H
Automatic Wire Bonders	L	L	M	H
VLSI IC Testers	-	L	H	H
Aligners	-	L	H	H
Mask Making, Inspection, and Repair	M	H	H	H
Chemical Plasma Etchers	-	M	M	H
Reactive Ion Etchers	-	L	M	H
Ion Milling	-	-	-	-
Computer Aided Design	L	L	H	H
Magnetic Sputtering	-	L	M	H
100+ Pin Packaging Know-How	-	-	L	H
High Power Packaging Know-How	-	-	L	M
Military-Optimized Design Know-How	-	-	L	M

We applied these weighting factors to figure 5 of the proof-of-concept paper, which related these 24 equipment types to specific anticipated Soviet weapons systems. By adding an additional weighting factor we differentiate between these equipments, hopefully avoiding a tendency toward weapons system columns filled with all stars. We combined this additional weighting factor with the two previous ones using a "weakest link" philosophy. The least important weighting factor determines the overall weight for any given chain connecting a weapons system to equipment through links of performance characteristic, subsystem, component, and technology. In contrast, when one equipment type is linked to a given weapons system by more than one chain—as is usually the case—we assign that equipment the greatest importance factor associated with any of the chains. Our "weakest link" weighting scheme is shown in table 2, while figure 1 shows the modified matrix which relates these 24 equipment types to specific Soviet weapons systems.

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**Table 2**

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L = LLL	M = MMM	H = HHH
= LLM	= MMH	
= LLH	= MHH	
= LMM		
= LMH		
= LHH		

Other weighting schemes are possible, and would be equally valid. Other schemes which have been explored include: "strongest link"; "all low is low, all high is high, all others are medium"; "two lows are low, two highs are high, all others are medium"; and "two lows are low, all high is high, all others are medium." Most of these other weighting schemes tend to classify every equipment as a high importance since the default value for multiple links to a given equipment is the value of the most important link.

○ Helpful  
● Important  
★ Essential

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